Magnetic Fields inside LPS Model of Truss Bridge by Direct Lightning: Simulations and Measurements

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This paper presents an evaluation of magnetic fields inside lightning protection systems (LPS) model of truss bridge resulting from direct lightning strikes. The simulation model is base on the coupled transmission line network in the frequency domain combined with the Fourier transform technique, which is employed to evaluate the electromagnetic transient surge current distribution in LPS. The transient magnetic fields are calculated based on Biot-Sarvat Law and finite difference method. The computed results were verified versus some experimental results for the reduced-scale model with return conductors (RSRC), and good agreement was found between the measured and the calculated results.

***Index Terms*—Lightning, lightning magnetic fields, lightning protection system, reduced-scale model, truss bridge.**

I. Introduction

Lightning represents a severe threat to the sensitive electrical or electronic equipment located inside a struck structure. Avaliable literatures mainly foucs on the EMC/EMI problems in buildings caused by lightning strikes[1], but the same issues in truss bridge should be concerned[2].

This paper adopts coupled transmission line network[3] to build the model of lightning protection system (LPS) of truss bridge. The solution to the whole LPS is formulated by using an iterative approach in the frequency domain, and the time domain waveforms of current in each conductor of LPS are obtained by IFFT (Fast Fourier inversion). The transient magnetic fields are calculated based on Biot-Sarvat Law and finite difference method. All the computed quantities verified versus the experimental results for the reduced-scaled model with return conductors (RSRC)[4].

II. Computational Approach

A. Current Distribution in Branch Conductors with Considering the Inductive Coupling

Fig.1 shows the geometry of reduced-scale model of truss bridge based on a scaling factor 1: 50, with dimensions of 2m ×1m×0.5m. In simulation, the conductor of the LPS is described using the coupled transmission line model, and can be reduced to an active two-port equivalent circuit.

With the purpose of providing a systematic and fast algorithm to predict the lightning current distribution in the LPS, the temporal trend of the current is taken to be characterized by the double exponential pulse

$$i = KI_0\left(e^{-\alpha t} - e^{-\beta t}\right) \tag{1}$$

Where K, I_0, α, β are suitable parameters, and can be determined via a numerical fitting method. The truncation frequency ω_{max} can be estimated using the following equation

$$20\log\left[\left|\frac{K(\beta-\alpha)}{(\alpha+j\omega_{max})(\beta+j\omega_{max})}\right|\right] = -200\text{dB} \tag{2}$$

The branches of the LPS are divided into a number of short segments, the length of which is shorter than the 1/10 of the wavelength of the truncation frequency. For example, the length of the segment is 1m for the lighting current with the parameter of 1/40μs, and the truncation frequency is approximately 19MHz.

Paper[3]concludes that the amplitude of mutual capacitive reactance is above five times greater than the self-capacitive reactance of each segment, and 40 times greater than the impedance in series of each segment. A lower frequency leads to a weaker influence of mutual capacitive coupling. one may draw the conclusion that the mutual inductive coupling effects are essential to the accuracy of the results, but the effect of mutual capacitive coupling is trivial, so it can be neglected. In this paper, the mutual inductive coupling effects are taken into account by adding a set of lumped voltage sources along the transmission line.

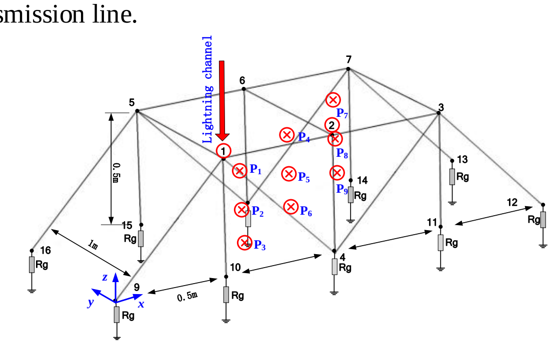

Fig. 1. Reduced-scale Model of Truss Bridge LPS（•：Current injection points: ①: corner. ②: mid_edge. ⊗: dH/dt sensor locations: P_1~P_9.

B. Magnetic Fields Computation

According to the transient current distribution in the branch conductors of truss bridge LPS, the transient magnetic fields distribution inside the truss bridge are calculated by means of Biot-Sarvat Law and finite difference method, and the time delay that exists between the current segment and the observation point is taken into account.

In simulation, the 1/40μs lightning current was adopted, and the lightning current injection point was in the mid-edge of roof. Fig. 2 shows the simulation results of magnetic flux density inside full scale truss bridge model (100m×50m×25m).

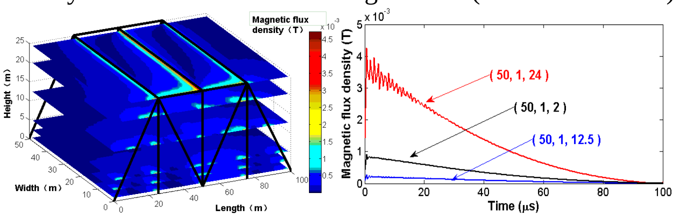

Fig. 2. The calculated results of magnetic flux density in full scale truss bridge model with the mid_edge injection (a) magnetic flux density on the six planes [z_1=0.01m, z_2=0.05m, z_3=0.1m, z_4=0.25m, z_5=0.4m, z_6=0.49m]. (b) magnetic flux density in three points[(50,1,2); (50,1,12.5); (50,1,24)].

With the oscillation of time domain magnetic flux density waveforms in Fig. 2(b), we can conclude that the perturbation effects in real truss bridge model are obvious. The mechanism for this phenomenon is resonance caused by the relationship between the electrical length of real truss bridge and the frequency band of magnetic fields waves.

III. EXPERIMENTAL SETUP

The verification experiments have been set up in the Aviation Key Laboratory of Science Technology on High Intensity Electromagnetic Environment Protection. Because of the limited size, it is not possible to build up full size LPS structures of truss bridge in high voltage laboratories. Therefore, a scaled model is used with reduced dimensions, using a scale factor 1:50, which is shown in Fig. 1. The injected current is generated by the impulse current generator, and applied to the roof of the steel structure [corner: (0.5, 0, 0.5) and mid-edge: (1, 0, 0.5) in meters]. The shape of current is damped oscillation, and the maximal amplitude of current is 200kA. The steel structure stands on a large steel plate, which simulates the perfectly conducting earth and ground resistance.

The model was placed on a wooden platform 1m above laboratory floor, In order to achieve a symmetric arrangement of the model with respect to the impulse current generator; the model had to be rotated by 90^o. (i.e. the roof is pointing to the left and the floor to the right) as illustrated in Fig3(a). An injection rod simulated the lightning channel and a current return path arrangement enabled the current to flow back to the impulse current generator. The magnetic fields associated with the current in return conductors will affect the test results. Minimize of this influence was obtained by quasi-coaxial arrangement multi-return path rods. The schematic is as Fig.3(b) shown. As the steel plate acts an equipotential surface, the current through the return conductors are almost symmetric and independent of the current injection point.

The components of magnetic flux density derivatives (dB/dt) were measured at nine locations inside the RSRC model, namely P_1 (0.6, 0.1, 0.4), P_2 (0.6, 0.1, 0.25), P_3 (0.6, 0.1, 0.1), P_4 (1, 0.5, 0.4), P_5 (1, 0.5, 0.25), P_6 (1, 0.5, 0.1), P_7 (1.4, 0.9, 0.4), P_8 (1.4, 0.9, 0.25), P_9 (1.4, 0.9, 0.1) with the coordinates in meters, as shown in Fig. 1. The *x*, *y*, and *z* components (definition of coordinates are shown in Fig. 1) of flux density were measured using shielded loop sensors. The signals were transferred to the digital oscilloscopes. The magnetic flux density *B* was derived from the d*B*/d*t* waveforms by numerical integration.

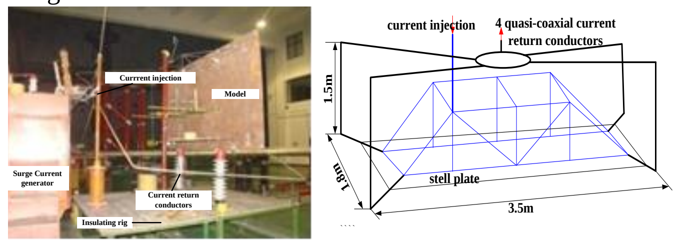

Fig. 3. Simulate structures (LPS). (a) Schematic representation of test setup with corner current injection and multireturn path rods (b) test setup in the laboratory

IV. BETWEEN EXPERIMENTAL AND COMPUTED RESULTS

In experiment, the amplitude of injected damped oscillation current was 49kA, as illustrated in Fig. 4(a), and the frequency of the damped oscillation current was about 6250Hz. Fig. 4(b) illustrates the mesured and calculated results of magnetic flux density waveforms at P_4 at the duration time of the first peak for mid-edge injection case. The biggest error between the simulated and measured componments of magnetic flux density is about 30% among the aforementioned nine measurement points..

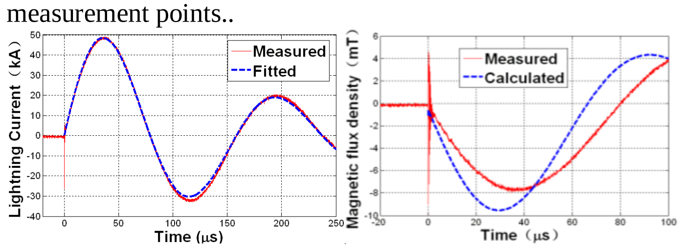

Fig. 4 Oscillograns of the measured and the computed (a) injectd current, (b) the y-component of the magnetic flux density at P_4 for mid-edge injection case.

V. CONCLUSION

For the RSRC model, the numerical simulations were found to be in good agreemnet with measured waveforms. For the full-scale model, the magnetic flux density waveforms exhibit osicillations due to the resonance frequency of the structure, and the propagation effects are more obvious than the RSRC model.

VI. REFERENCES

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